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Some electrical and magnetic studies of Kilauea Iki lava lake, Hawaii

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By

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Some electrical and magnetic studies of Kilauea Iki lava lake, Hawaii

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In recent years, the U.S. Geological Survey has been applying various electrical-magnetic (E-M) geophysical techniques to the study of volcanologic processes at Kilauea Volcano, Hawaii. Some of these studies have been directed towards determining the responses of these E-M methods on the cooling and crystallizing lava lake that formed in Kilauea Iki pit crater in 1959 (Richter and others, 1970). Over the years, this 111 meter-deep ponded body of basaltic magma has served as a natural laboratory for petrologic, geochemical, and geophysical investigations (Wright and others, 1976), and hence, has yielded some control for interpreting the resulting E-M data gathered in these studies.

In the following, a brief discussion of the application, results, and some tentative conclusions of these studies is presented. A more detailed report on these data is being prepared. The primary purpose of this report is to make all of these data available to others who may consider applying similar techniques in studies of Kilauea Iki or other ponded lava lakes. These data not only provide some insights into the in-situ bulk physical properties of the lava lake, but may also aid in establishing some design criteria for E-M experimental studies that would be contemplated in the future.

An index map of Kilauea Iki with the location of the various E-M studies reported here is shown in figure 1.

VLF (very low frequency) induction studies

The tilt angle and ellipticity of the polarization ellipse of the magnetic field from VLF transmitting station NLK (frequency = 18.6 kHz; azimuth = N34°E) was measured over the lake surface using a Geonics EM 16 receiver.[1/] This technique has proven to be a useful tool in delineating near-surface, still-hot intrusions in other parts of Kilauea (Zablocki, 1975). A resulting contour map of the tilt angles (fig. 2) clearly shows the large responses toward the edges of the ionically conductive magma lens (depth to top of magma is ∿44 metres as determined from holes drilled through the crust in February 1975 by the U.S. Geological Survey). Only those edges of the lake that are approximately in-line with the azimuth of the transmitter produce a vertical magnetic field component, and hence, a tilt angle greater than zero. The large responses toward the northwest edge of the lake are developed because the long, lateral extent of this side is relatively more parallel to the stations azimuth. It is noted that the tangential magnetic field is refracted by about 25° along this edge of the lake.

A set of 16 reference nails were placed in-line at ∿10 metre (33.3 ft) intervals along a N34°W traverse that passed through reference nail location 29N2 where the tilt angle response is large. VLF measurements repeated annually between 1972 and 1976 have shown no noticeable changes along this traverse (fig. 3). Considering the slow rate of cooling of the magma over this time interval, it isn't surprising that changes in the tilt angle are not detectable.

1/ Use of brand names in this report are for descriptive purposes only and in no way constitutes endorsement by the U.S. Geological Survey.

Computer derived two-dimensional model studies indicate that the surface projection of the edge of the magma lens in the area may be approximately 20 metres southeast of reference nail 29N2, or about 115 metres from the edge of the lava lake surface (fig. 3). A similar lateral distance is inferred from the VLF response near nail location 11N4 and near 17S6.

Two VLF induction resistivity profiles (station NLK) were made along traverses between reference nails 0 through 40 and 17S7 through 17N12 using a Geonics EM16R receiver (fig. 4). Salt water-saturated sponges were used to reduce the contact resistance of the electric field measuring probes on the high resistivity lava surface (>25,000 ohm-m). Notwithstanding the 2 X 10^7 ohms input resistance of the electric field preamplifiers, some of the scatter in the measurements may have been caused by impedance loading. The approximate edges of the conductive lens appear to be defined near stations 17N10, 17S6, and 5 where the measured resistivities increase rapidly. In contrast, the resistivities only gradually increase toward the west end of the lake where the lake is shallower and the magma lens is thinner, or in places, may even be solidified.

Galvanic resistivity studies

Two vertical electrical resistivity Schlumberger soundings (VES) were made on the central portion of the lava lake surface. One sounding was expanded in an east-west direction from reference nail 17 to a maximum half-current electrode spacing, AB/2, of 152 m (500 ft). A similar sounding was expanded in a north-south direction from reference nail 17N1. The potentials were measured with a pair of non-polarizing porous pots filled with copper sulfate ($Cu/CuSO_4$) connected to a high impedance digital voltmeter and the current was supplied from a small, lightweight 1000 VDC @ 150 milliampere power supply. Contact to the lake surface was obtained via salt water-saturated canvas bags.

In detail the observed sounding curves (figs. 5 and 6) are similar, but not identical and differences in the measured resistivities may result from lateral inhomogeneities. These sounding curves were combined into an average curve after smoothing each curve for the discontinuities resulting from near-surface effects when the potential electrodes were expanded.

Temperature data obtained from holes drilled through the crust and into the melt in February 1975 were used to provide constraints in interpreting the averaged sounding curve. Specifically, a computer-derived model was chosen that required a very high resistivity layer to be present between 35 metres (115 ft) and 44 metres (145 ft). This zone corresponds to the average temperature interval of 150° and 950° C where the lavas are relatively dry and their intrinsic conductivity is low. One possible interpretation of the geoelectric section is shown in figure 7.

In another brief study, the contact resistance of a stainless steel casing that was set into the melt in drill hole KI-75-3 in April 1975 was measured. Using a 60 Hz low-powered oscillator and an A.C. millivoltmeter, the resistance between two grounded electrodes placed in the soil near the north edge of the lava lake and the resistances between those electrodes and the steel casing yielded a value of less than 35 ohms (3 equations with 3 unknowns) for the contact resistance. The purpose of this experiment was to assess the applicability of making a "misse la mass" type of survey in the future for outlining the lateral extent of the ionically conductive magma. The low contact resistance together with the observation in January 1976 that the steel casing had sank about 0.4 metres down the hole since October 1975 must mean that the bottom of the casing is in direct contact with the melt. Therefore, it is expected that this experiment would yield good results for outlining the edges of the melt.

Self Potential studies

Self potentials were measured at reference nail locations 0 through 40 (E-W) and 17S8 through 17N13 (N-S). A reference electrode was established in soil at the base of the Kilauea Iki trail near reference nail 0. Positive potentials (with respect to the reference electrode) in excess of 300 millivolts are generally developed over the bulk of the lake and tend to be lower toward the edges (fig. 8). The short-wave length variations of the potentials are not characteristic of data obtained in other parts of Kilauea and may result from abrupt changes in near-surface resistivities or from the complex nature of a convecting system in the hydrothermal zone above the melt (Zablocki, 1976). Perhaps it is fortuitous, but there appears to be a bi-lateral symmetrical distribution in the potentials centered to either side of reference nail 16 and 17N2 along the respective profiles. A more detailed study would clarify this observation.

In-hole self potentials were measured in drill hole K1-75-1 to a depth of 33 metres (108 ft). A Ag/Ag Cl electrode pair was used where the fixed reference electrode was placed on the lake surface near the drill hole collar. The in-hole electrode was wrapped with a large damp cloth for making ohmic contact to the borehole wall and suspended from an insulated copper-clad steel wire. Potentials were measured with a high impedance (10^{14} ohms) digital voltmeter. All of the in-hole potentials were positive with respect to the reference electrode and had an average value of 275 millivolts except at 6 metre depth (20 ft) where the potential decreased to 72 millivolts (fig. 9). If these potentials are referred to the reference electrode used in the surface studies (fig. 8), then the in-hole values will be approximately +600 millivolts. The large positive potentials are in accord with the magnitudes and polarity of self-potentials measured in other parts of Kilauea over known or inferred hot zones and may result from preferential absorption of anions or other means of effecting the differential displacement of cations from anions (Zablocki, 1976).

Magnetic studies

Total field magnetic intensities were measured over most of the lake surface with a Geometrics model G816 portable proton magnetometer.[1/] A contour map shows the distribution of the intensities at 2.44 metres (8 ft) above the lake surface (fig. 10). The 4500 gamma gradient results from topographic effects of the steep-walled crater. Annually repeated measurements along the north-south 17 line showed a consistent decrease in intensities at all measuring locations (fig. 11a). This decrease can be reconciled with the annual secular variation (approximately -25 gammas per year). Any changes due to a lowering of the Curie isotherm as the lavas cool should have resulted in an increase in intensities.

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Measurements were also made at 3 and 2.44 metres (10 and 8 ft) elevation from the lake surface along the north-south 17 line (fig. 11b). Most of the variations in the vertical gradient (differences in field intensities at these two elevations) can be ascribed to near-surface changes in magnetization. The computed anomalous vertical gradient at the north and south edges of the paramagnetic lens would be approximately 10 gammas/m (positive on the south and negative on the north edges). Thus, the relatively large near-surface changes in magnetization would probably preclude using this technique for defining the lateral extent of the magma.

Additional magnetic studies made included in-hole continuous magnetic susceptibility and vertical magnetic field intensity measurements in drill holes KI-75-1 and KI-75-2 (not shown here). These studies showed that the magnetic properties vary widely within a single hole and between holes, only about 200 metres apart. These variations were not unexpected considering the complex history of the Kilauea Iki eruption. The most significant finding of these studies was in establishing the apparent Curie temperature of the Kilauea Iki lava to be approximately 540°C.

References

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Wright, T. L., Peck, D. L., and Shaw, H. R., 1976, Kilauea lava lakes: natural laboratories for study of cooling, crystallization, and differentiation of basaltic magma: Amer. Geophys. Union Monograph, Wollard Symposium, in press.

Zablocki, C. J., 1975, Inferences on the configuration of some recent magma intrusions in Kilauea volcano from VLF induction measurements: (Abstract), Am. Geophys. Union Trans., v. 56, no. 12, p. 1070.

______1976, Mapping thermal anomalies on an active volcano by the self-potential method, Kilauea, Hawaii: Proceedings of the Second U. N. Symposium on the development and use of geothermal resources, San Francisco, Calif., 20-29 May 1975, in press.

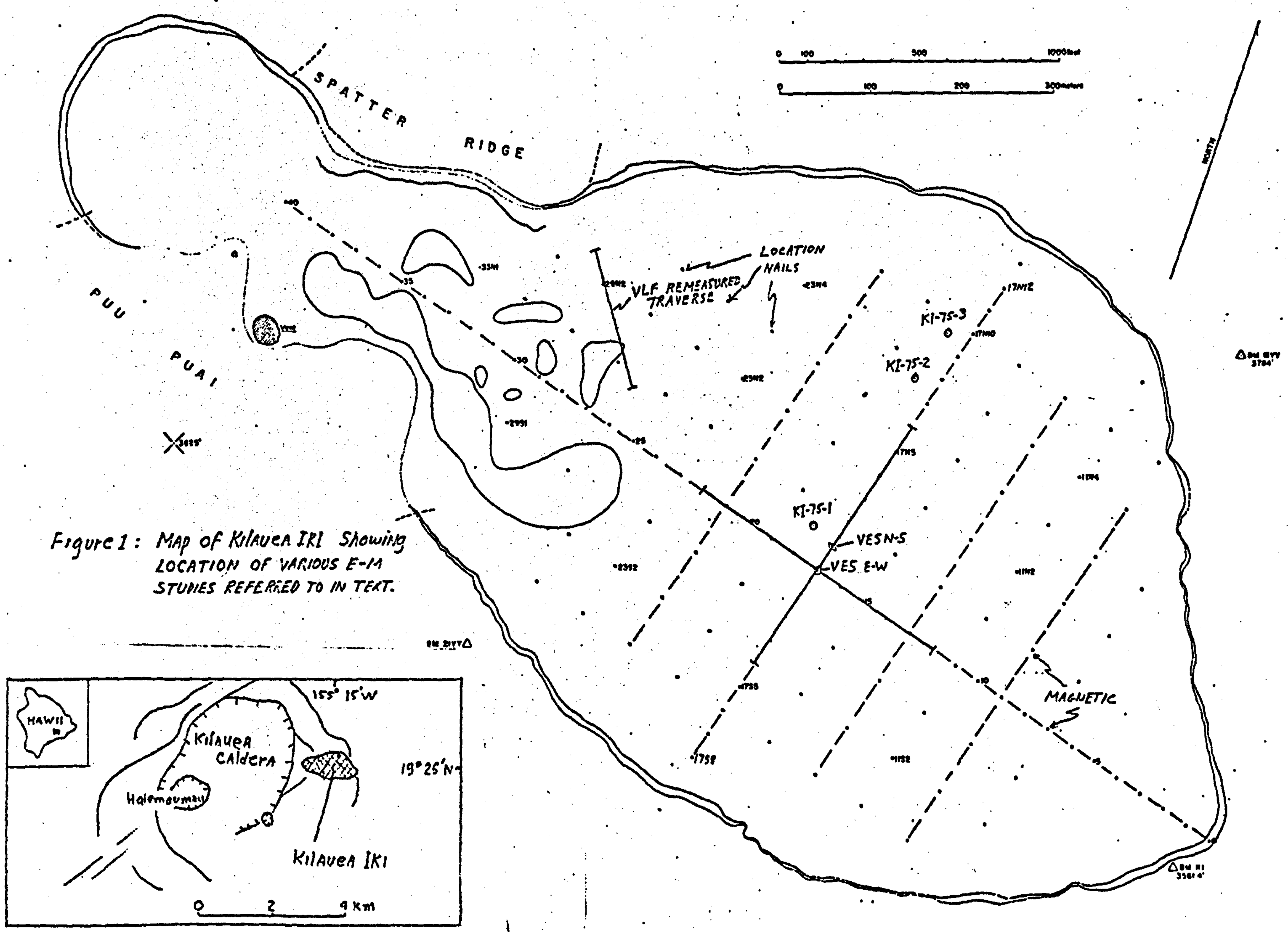


Figure 1: Map of Kilauea IKI Showing LOCATION OF VARIOUS E-M STUDIES REFERRED TO IN TEXT.

INDEX MAP

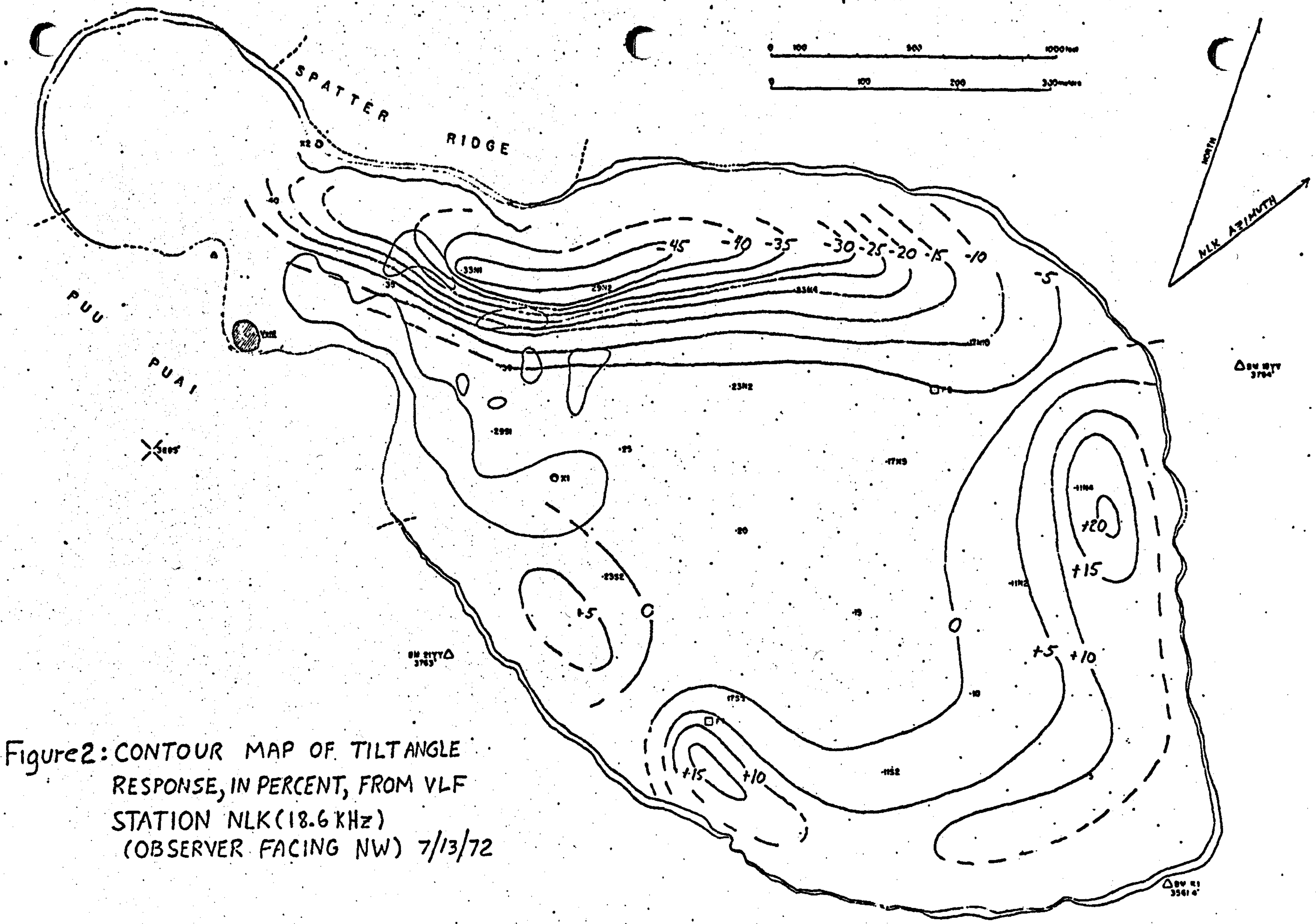


Figure 2: CONTOUR MAP OF TILT ANGLE RESPONSE, IN PERCENT, FROM VLF STATION NLK (18.6 KHz) (OBSERVER FACING NW) 7/13/72

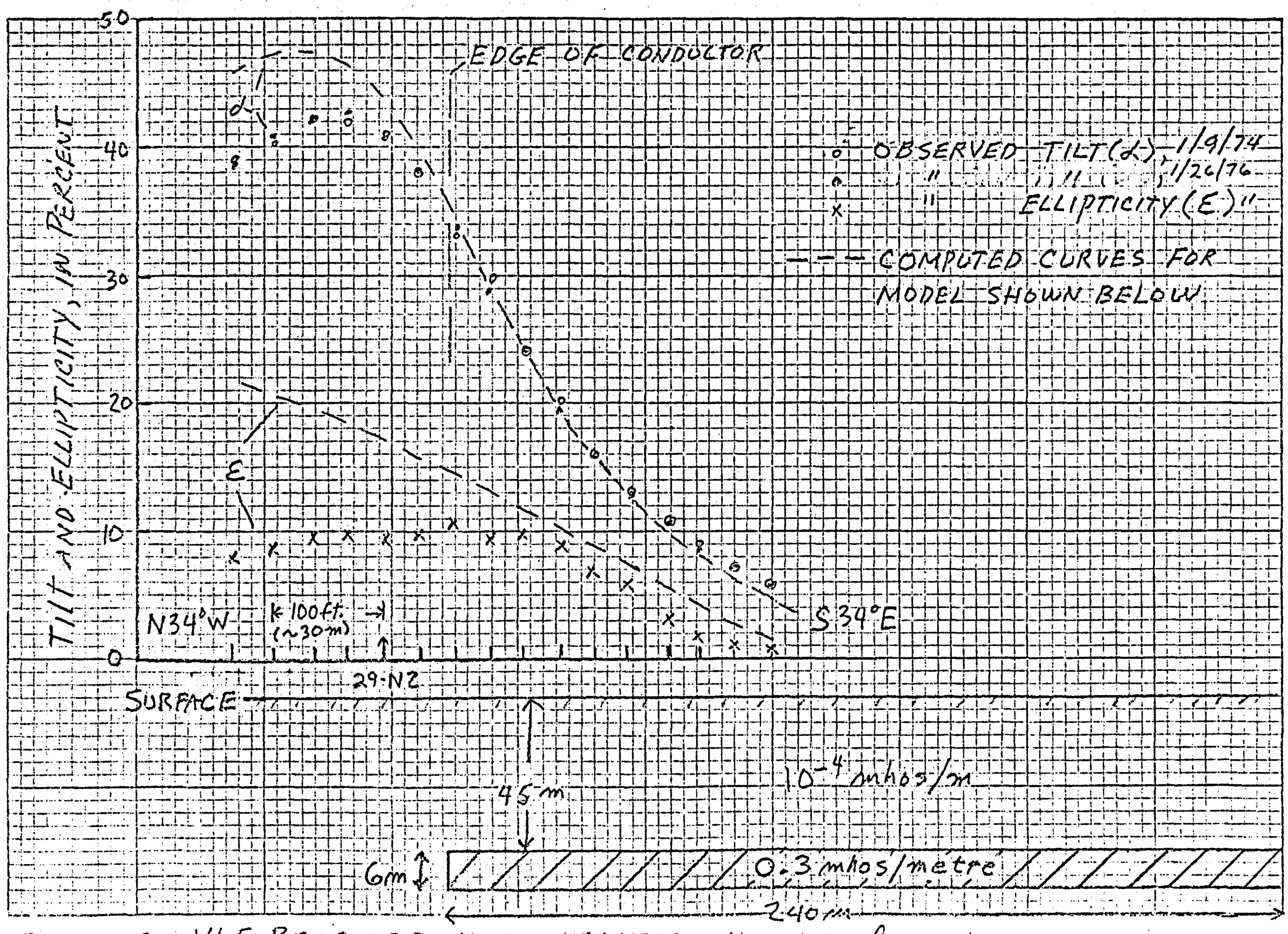


Figure 2. VLF RESPONSE ALONG TRAVERSE SHOWN IN figure 1.

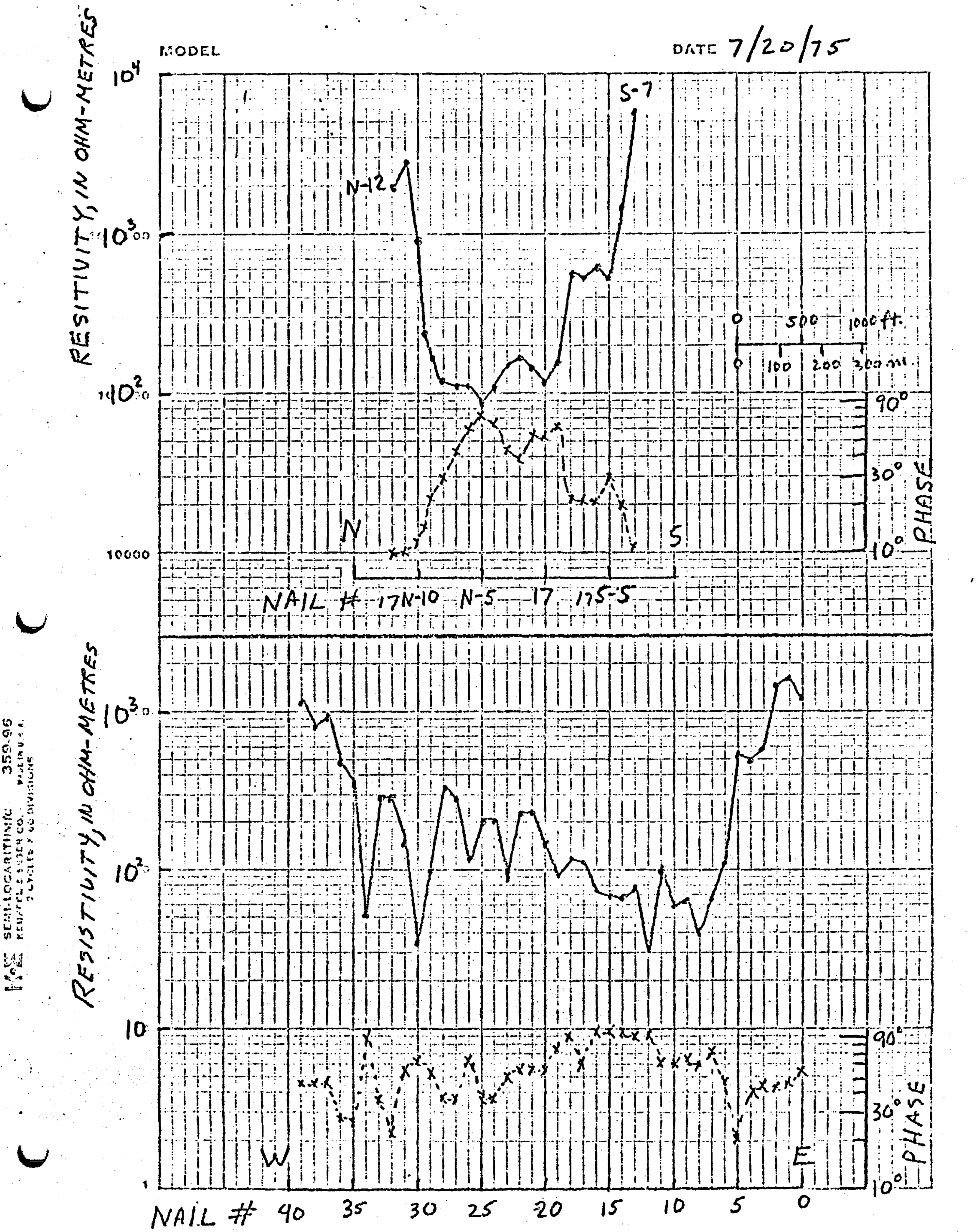
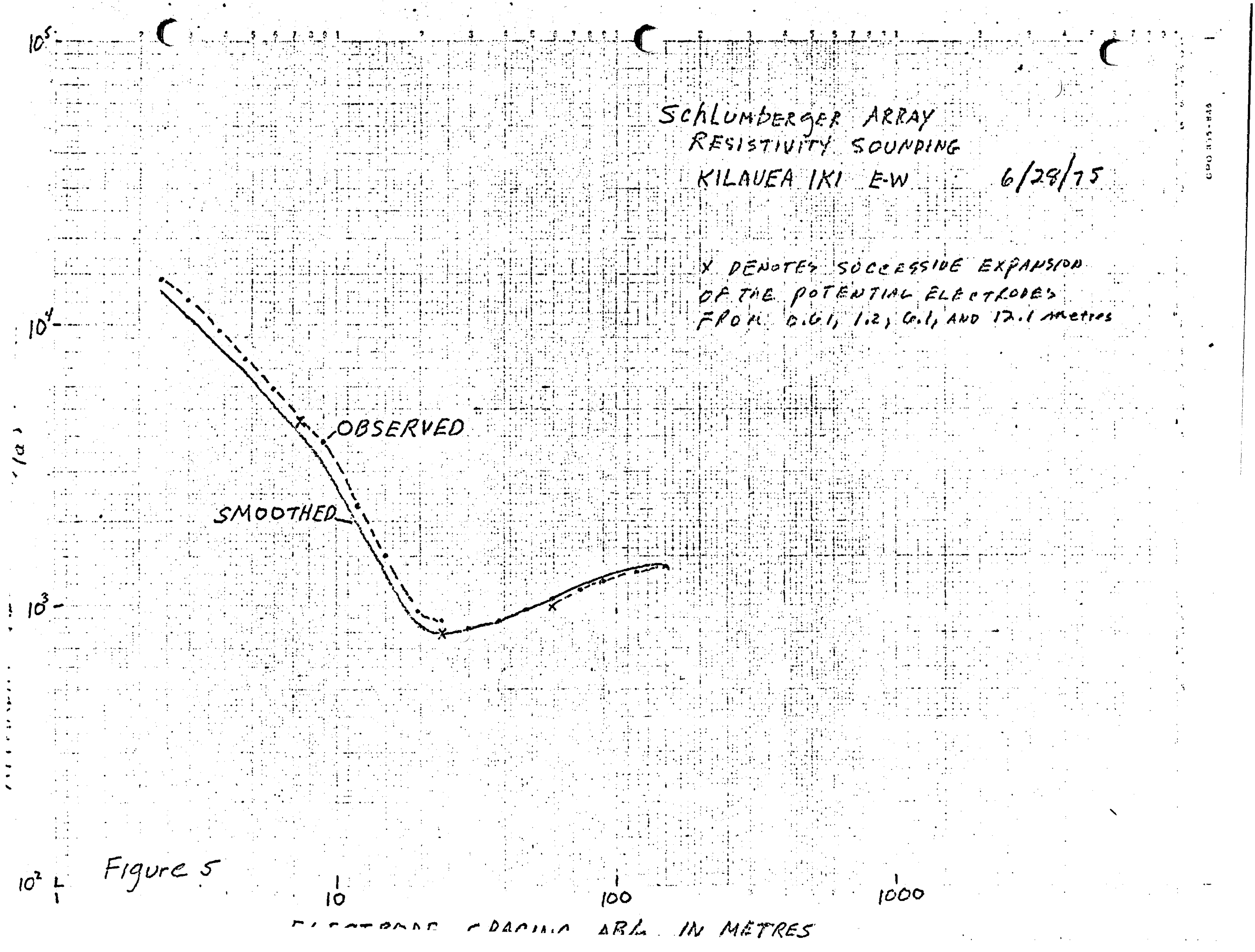
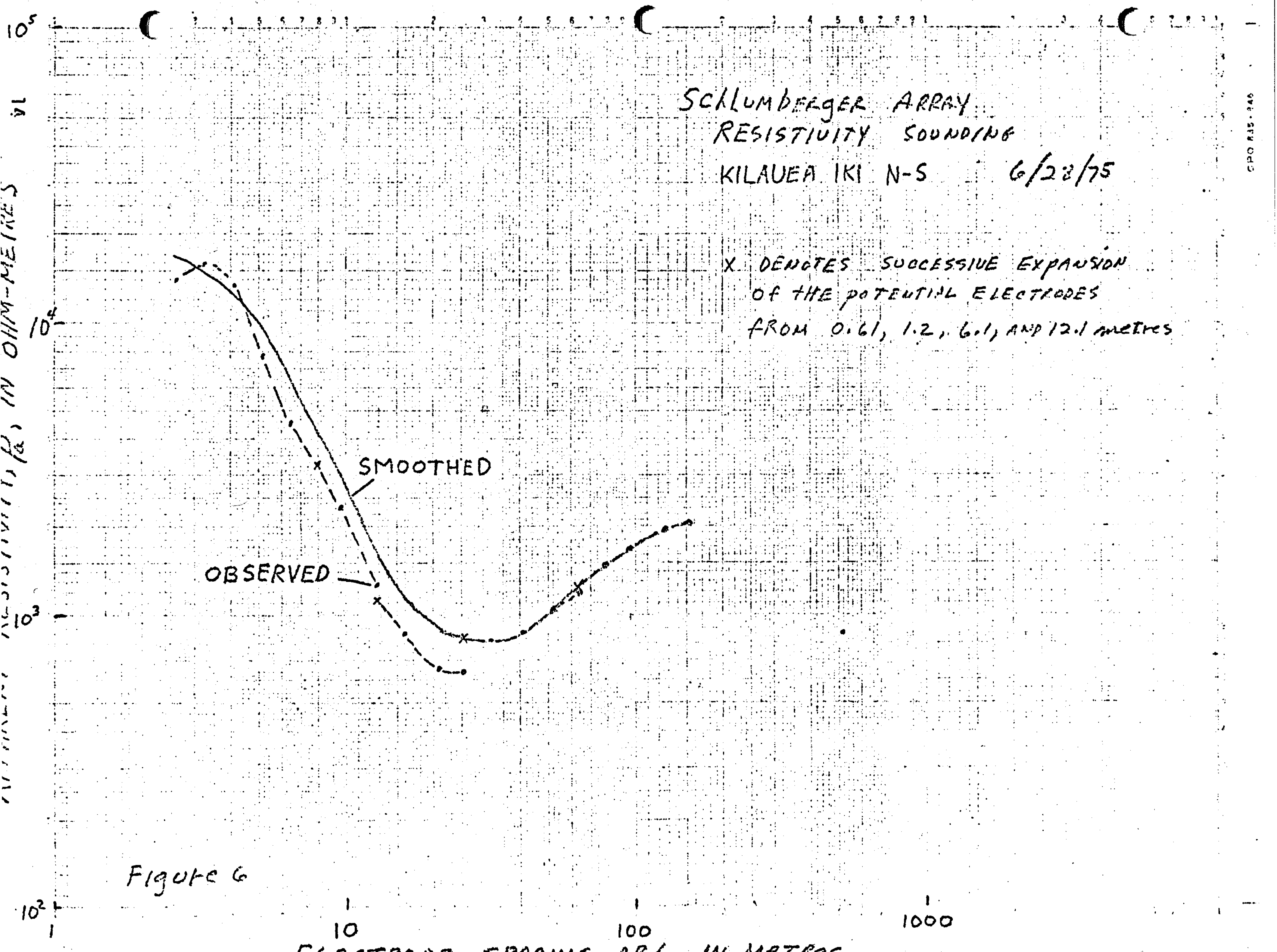


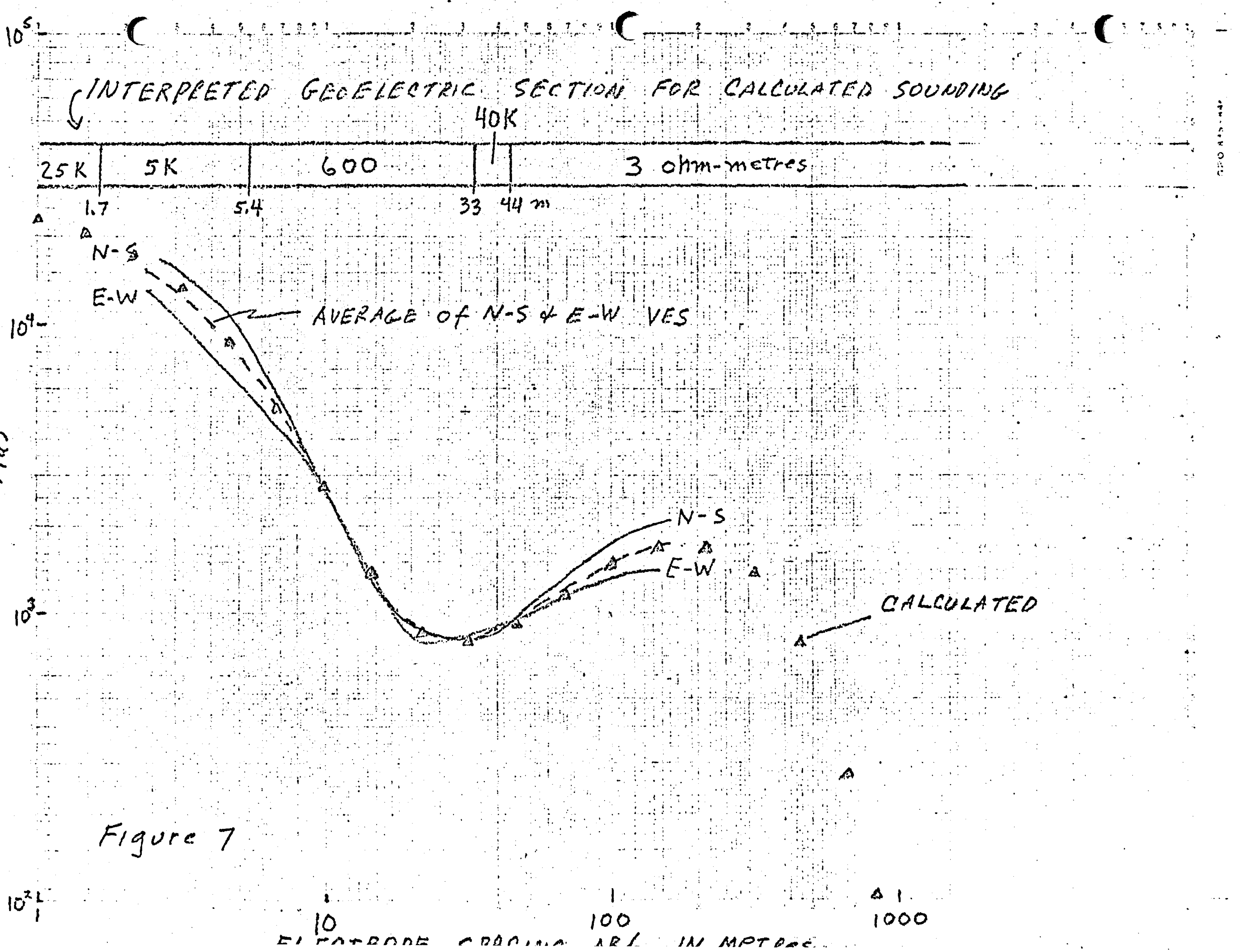
Figure 4: VLF INDUCTION RESISTIVITIES OBTAINED WITH GEONICS EM16R RECEIVER ALONG TRAVERSE INDICATED.



SCHLUMBERGER ARRAY
RESISTIVITY SOUNDING
KILAUEA IKI E-W
6/28/75
X DENOTES SUCCESSIVE EXPANSION
OF THE POTENTIAL ELECTRODES
FROM 0.61, 1.2, 6.1, AND 12.1 metres
OBSERVED
SMOOTHED
10^5
10^4
10^3
10^2
1
10
100
1000
IN METRES

Figure 5


SCHLUMBERGER ARRAY
RESISTIVITY SOUNDING
KILAUEA IKI N-S 6/28/75
X DENOTES SUCCESSIVE EXPANSION
OF THE POTENTIAL ELECTRODES
FROM 0.61, 1.2, 6.1, AND 12.1 metres
SMOOTHED
OBSERVED
10^5
10^4
10^3
10^2
1
10
100
1000
IN OHM-METRES
Figure 6



INTERPRETED GEOELECTRIC SECTION FOR CALCULATED SOUNDING
40K
25K
5K
600
3 ohm-metres
1.7
5.4
33
44 m
N-S
E-W
AVERAGE of N-S & E-W VES
N-S
E-W
CALCULATED
10^5
10^4
10^3
10^2
10
100
1000

Figure 7

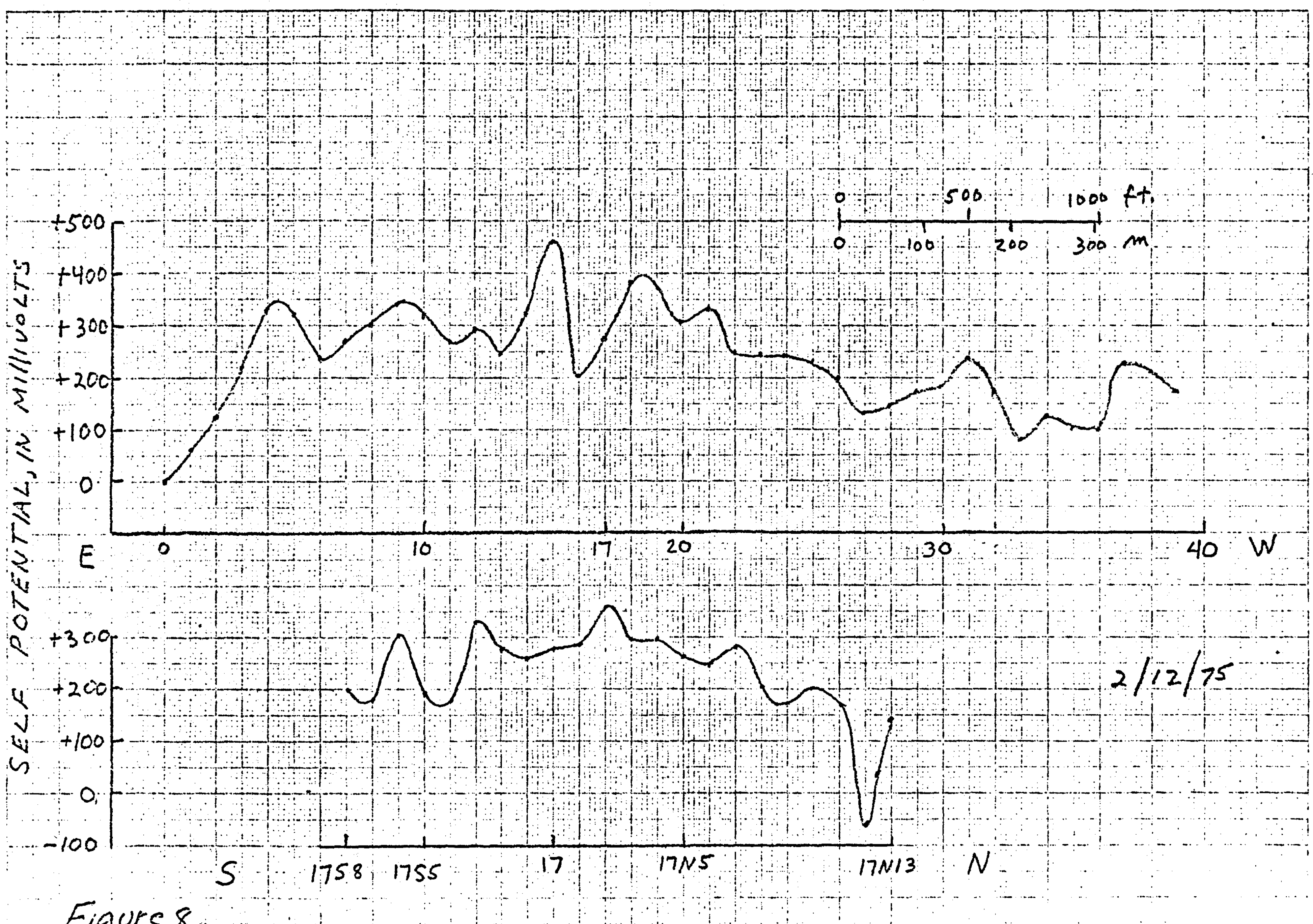


Figure 8

SELF-POTENTIAL PROFILES ON KILAUEA IKI LAVA LAKE SURFACE

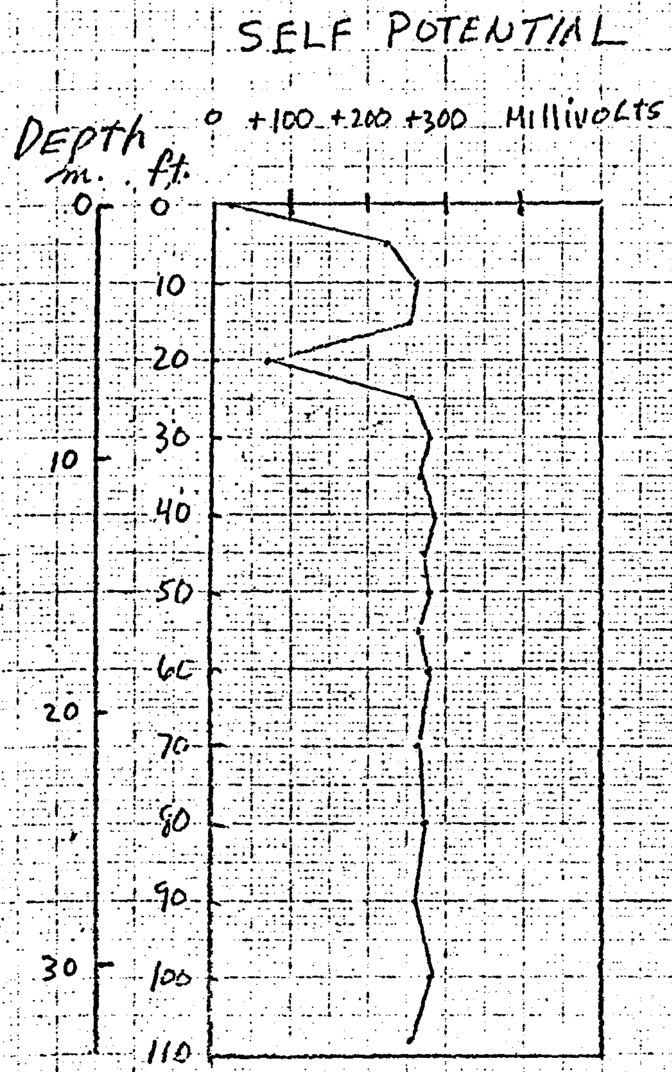


Figure 9: SELF POTENTIALS IN DRILL HOLE KI-75-1
(REFERENCE ELECTRODE 1 METRE LATERALLY FROM COLLAR AT SURFACE OF HOLE.) 5/9/75

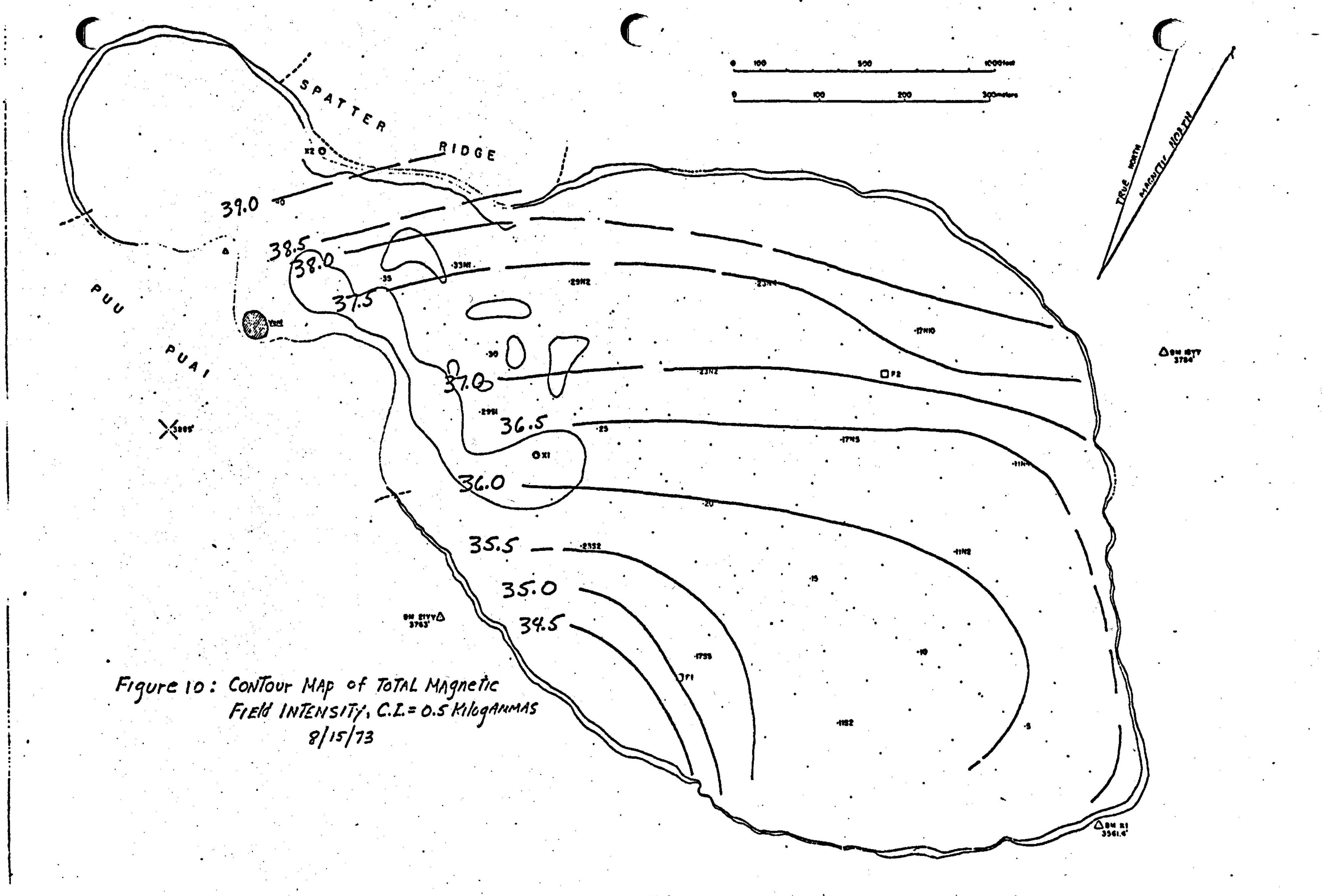
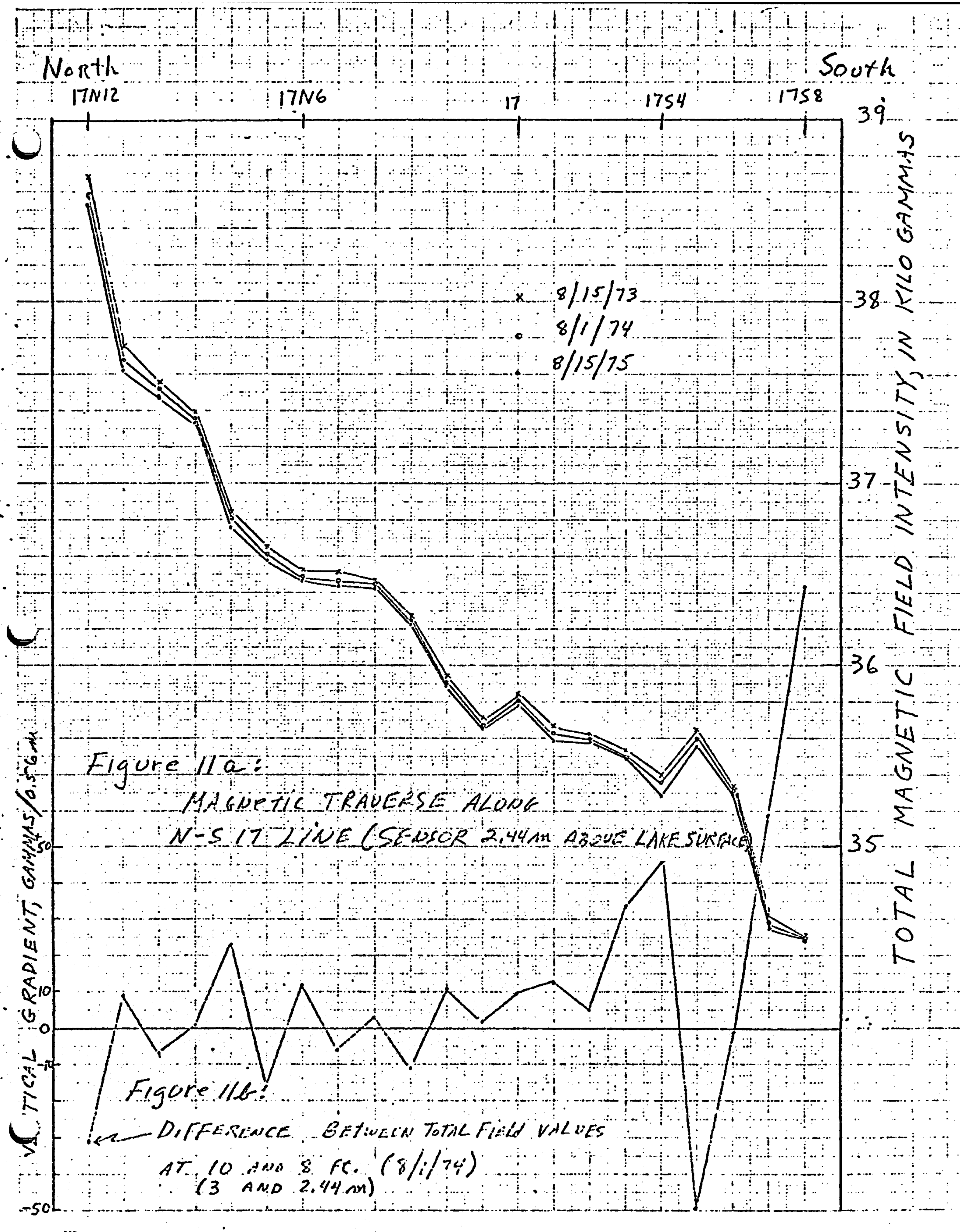


Figure 10: Contour Map of Total Magnetic Field Intensity, C.I. = 0.5 Kilogammas
8/15/73



North
South
17N12
17N6
17
17S4
17S8
39
38
37
36
35
x 8/15/73
o 8/1/74
• 8/15/75
TOTAL MAGNETIC FIELD INTENSITY, IN KILO GAMMAS
VERTICAL GRADIENT, GAMMAS/0.56 m
50
10
0
-10
-50
Figure 11a:
MAGNETIC TRAVERSE ALONG
N-S 17 LINE (SENSOR 2.44m ABOVE LAKE SURFACE)
Figure 11b:
DIFFERENCE BETWEEN TOTAL FIELD VALUES
AT 10 AND 8 FT. (8/1/74)
(3 AND 2.44 m)